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Manufacturing Implementation of Corona Oxide Silicon (COS) Systems for Diffusion Furnace Contamination Monitoring

Richard G. Cosway and Kelvin B. Catnull,
Motorola MOS12 Die Manufacturing,
1300 N. Alma School Rd.,
Chandler, AZ 85224

Gregory Horner and Brian Letherer
Keithley Instruments Inc.,
30500 Bainbridge Rd.
Cleveland, OH 44139

Abstract -- Maximizing production utilization of manufacturing tools is of vital importance to the economic health of a wafer fabrication facility; however, preventative maintenance and qualification is important to maintain the highest quality product from these tools. This imposes contradictory constraints on the time allocated to preventative maintenance qualification activities. For diffusion furnaces, the standard procedure is to utilize high-frequency capacitance-voltage (CV) measurements to assess the overall cleanliness of the quartzware. This requires an oxide to be grown in the furnace on test wafers usually without the presence of product. Following this, additional processing of these wafers is necessary to generate a structure which can be probed (electrode deposition, doping, pattern, and etch) and some type of furnace cleaning cycle is run for each boat in the system. Depending upon the type of furnace, the total time that product cannot be run can amount to one day and, depending on the qualification cycle, this hit in manufacturing time can occur each week, every two weeks, or every month. Once the furnace returns to manufacturing for running production, an additional delay is encountered prior to learning the outcome of the CV results, potentially resulting in material being run through the furnace out of specification. By utilizing a state-of-the-art Corona Oxide Semiconductor (COS) system for furnace qualifications, we have been able to cut our qualification time from 26.5 hours to 2.5 hours per week and have effectively increased our furnace capacity. This has been possible mainly due to the much faster turnaround of furnace contamination results which minimizes the need for unnecessary furnace cleaning. In addition, due to the more reliable nature of the COS measurements, fewer wafers are processed than were necessary when running CV's. We will also show results for utilizing a manufacturing process to grow oxide running product simultaneously for the qualification and comment on potential for recycling measurement wafers due to the lack of frontside contact in the COS measurement scheme.

INTRODUCTION

Diffusion furnace operations possess a marked difference from those of other process areas within a modern wafer fabrication facility. While many other process disciplines are carried out in single-wafer or small-batch tools, diffusion continues to use large batch sizes with many new 200-mm tools increasing load sizes to 150 to 200 wafers.

The larger batch sizes translate into larger risks associated with equipment issues. Equipment malfunctions or contamination issues place more product at risk within diffusion processes than most other areas within the fab.

The higher risk associated with furnace operations results in more concern for the timely and accurate completion of preventative maintenance measures. A major part of the preventative maintenance is the periodic evaluation of contamination which can result in a profound change in the electrical properties of the films grown within these tools. These are referred to as "electrical contamination".

Examples of "electrical contamination" include metallics which can generate energy states within the bandgap of the silicon substrate. In addition to the lifetime degradation associated with this phenomenon, the formation of interface-trapped charge (D_{it}) at the interface between the substrate and oxide also occurs. These surface states degrade the transconductance of CMOS devices due to decreased channel mobility.

The presence of oxidants (most notably O_2) in inert gas lines results in increased fixed oxide charge due to the presence of additional free oxygen within the oxide. The change in fixed oxide charge in turn results in changes in the threshold voltages of devices fabricated with this oxide and an associated decrease in device performance. This performance degradation is due to the threshold voltages changing in the same direction for both n- and p-channel devices creating threshold asymmetry.

Alkali impurities, such as Na and K, are probably the most significant concern in diffusion operations due to the ease with which problems can be introduced. Inappropriate handling of quartzware or wafer handling equipment is all that is necessary to introduce these mobile charges into the furnace environment. Devices fabricated with oxides grown with these impurities possess unstable threshold voltage characteristics due to the mobile nature of these charges at operating temperatures and fields.

Cleaning of diffusion furnaces to address metallic and alkali contamination is accomplished by the use of high-temperature steam cleans. These cleans actually utilize combinations of steam and HCl at high temperatures to increase the volatility of the contaminants. These cleans are quite time-consuming when sufficient time is provided at the elevated temperatures to maximize their usefulness.

Timely monitoring of all forms of "electrical contamination" is of vital importance. The longer the cycle time needed to determine the presence of contamination, the more product at risk. Due to the inherent long cycle time of conventional furnace contamination monitoring, steam cleans are often utilized without prior knowledge of the furnace cleanliness.

EXPERIMENTAL

Traditionally, furnace cleanliness has been evaluated using the high-frequency capacitance-voltage (CV) technique due to the simple instrumentation needed. In this approach, metal- or poly-

gated Metal Oxide Silicon CAPacitors (poly MOSCAPs) are fabricated using oxide grown in the furnace of concern. Metal-gated capacitors have the advantage of reduced cycle time and less modification to the oxide being measured than poly-gated capacitors; however, poly-gated capacitors are more representative of actual MOS devices fabricated in modern factories. All of the data presented will be for poly MOSCAPs. The overall high-frequency CV measurement setup is shown in Figure 1.

A bias is applied at elevated temperature (200 - 300C) in order to move the alkali impurities between the poly/oxide and oxide/substrate interfaces. Between movements of these impurities, the capacitance versus voltage characteristics are obtained. The CV plots exhibit a shift along the voltage axis after each stress, and the magnitude of the shift is used to indicate the total number of ions moved.

Due to the complex nature of the electronic states in the poly MOSCAP, the mobile charge level is not determined exactly through high-frequency CV measurements only. To effectively use this measurement, low bias levels (<2 MV/cm) are used and assumptions are made about the low probability for trap formation. Under these conditions, all of the flatband voltage shift between positive and negative bias-temperature stress conditions is assumed to be related to alkali movement. Using only the high-frequency curve, qualitative evaluation of the presence of interface-trapped charge can be made by observation of a skewing of the post-stressed CV curve in the transition region between accumulation and inversion compared with the unstressed curve. In practice, no exact values can be determined.

Oxide thickness can be determined from the capacitance in accumulation. Parasitic resistances within the poly gate and the probe setup can result in an attenuation of the capacitance signal resulting in an overestimation of the oxide thickness.

Another drawback of the poly MOSCAP approach is that the additional processing necessary for their formation may itself introduce changes in the electronic state of the oxide.

The Corona Oxide Silicon (COS) measurements resemble the low-frequency CV technique more than they do conventional high-frequency CV measurements[1]. Low-frequency CV measurements are not used for normal furnace monitoring due to the additional leakage sensitivity compared with high-frequency measurements.

The overall COS measurement setup is shown in Figure 2. This approach does not require that a conductive gate be deposited on the oxide to be tested. Instead, air is ionized through the use of a corona source and these ionized molecules are deposited on the oxide surface. In the case of positive ions, H_3O^+ is created from ionization of moisture while in the case of negative ions, CO_3^- is created through the ionization of CO_2 [2]. This charge biases the oxide in a controlled fashion, and is analogous to the voltage applied to the gate of a poly MOSCAP.

The corona bias does not result in the oxide sustaining an unrepresentative voltage as summarized in Figure 3. Despite the 8 KV used to ionize the air, the mean free path of these ions is approximately 0.5 μ m. The 4 cm distance from the corona source to the wafer surface efficiently reduces the kinetic energy of the ions to near thermal equilibrium. The absence of damage is verified by consecutive D_{it} measurements on one wafer site. D_{it} , a sensitive

indicator of oxide stress-induced damage, does not increase during repetitive measurements.

Once the charge (Q) has been deposited on the oxide surface, the surface voltage (V_s) is measured using a mechanical oscillator and an auto-nulled vibrating Kelvin probe.

The extent of band bending, determined as changes in capacitance in the conventional CV technique, are measured using surface photovoltage (SPV). A plot of the SPV vs. surface voltage provides much of the data obtained from the complete CV curve.

Mobile charge is measured with the COS technique by "pushing" all of the mobile charge to the oxide/substrate interface using a positive corona and heating the wafer to 250C following a surface voltage measurement. A "pull" corona is applied, the wafer is heated to 250C, and the surface voltage is remeasured. The surface voltage difference is then a measure of the extent of alkali movement.

Additional parameters can also be obtained from the V_s -Q and SPV-Q curves. The oxide thickness is obtained from the slope of the surface voltage vs. deposited charge plot without the errors associated with parasitic resistances observed for high-frequency CV measurements. The flatband voltage is obtained from the position where SPV = 0, indicating no band bending in the silicon. The interface-trapped charge is obtained from the slope of the V_s -Q curve in the depletion region. A summary of the sources of these parameters is shown in Figure 4.

Note that all measurements are made without the need to contact the front surface of the wafer. This minimizes the potential for cross-contamination between wafers and makes the reuse of test wafers possible.

The total cycle time from oxide grown to electrical measurement for a three-site measurement is 2 - 4 days for poly MOSCAPs using high-frequency CV measurements and approximately 0.6 hours for COS.

All measurements were made using a Keithley Quantox.

RESULTS

The data presented is for typical vertical furnaces running 200-mm p-type wafers. These dual boat, single tube systems traditionally required 26.5 hours of qualification time each week.

A schematic of the original qualification procedure is shown in Figure 5. First a robot calibration is performed taking about 0.5 hours, then an 8-hour CV oxide cycle is used to grow the qualification film. Since CV data is not available for a few days, a subsequent steam clean is performed on each of the boats. Each clean takes about 8 hours. Finally a mass flow controller (MFC) calibration is performed taking 2 hours before the furnace is released back to manufacturing.

The first area of emphasis was in replacing the CV measurements with COS. The benefits of this included the reduction in cycle time already mentioned as well as the ability to obtain more believable data that is free from operator errors which traditionally plague CV plotting. This increase in data integrity

enabled a change from running two CV wafers to a single COS wafer resulting in test wafer savings. Additional processing of CV wafers was also eliminated which, in addition to increasing the measurement cycle time, normally consumes valuable fab capacity which could be used to run product.

In addition to the savings in wafer process time, measurement throughput is enhanced with the COS system as shown in Figure 6. Even though the initial purchase price of the COS system is more than CV, the increased throughput can offset this cost with high run rates of furnace monitoring wafers. Part of the cost offset comes from elimination of the need for \$3,000 per month in replacement CV probe needles and part comes from the improved measurement reliability which enables a reduction in the total number of furnace monitoring wafers processed.

The next area of emphasis was the elimination of steam cleans. As long as the COS results are available and in control prior to the completion of the MFC calibration, the furnace is returned to manufacturing immediately after that calibration. This eliminates 16 hours of qualification time each week. The results in Figure 7 are weekly average mobile charge values across several furnaces obtained using CV, COS, and SIMS techniques. These show that for two different processes run over several weeks in furnaces without steam cleans, there is no associated increase in alkali levels over time. Note in this figure that the COS and SIMS results are for oxide only while the CV results are for the same wafers processed through the complete poly MOSCAP flow.

The final area of emphasis was to convert the CV oxidation process to a production process. While the COS mobile charge control limits were different among the processes, the control within a given process was comparable in terms of variation. This similarity was also noted when comparing high-frequency CV to COS measurements as shown in Figure 8. The conversion to use of a production recipe saved an additional 8 hours of qualification time each week. A schematic for the final qualification procedure is shown in Figure 9.

As evident in Figure 7, there are differences between the mobile charge determined from CV and COS measurements. These differences can be broken down into processing, electrical, and measurement algorithm issues.

The processing of poly MOSCAPs requires the poly gate deposition and doping. The poly deposition includes an HCl pre-clean and it was shown in previous work [3] that this results in removal of alkalis residing at the surface of the oxide. In addition, the POCl_3 used for doping the poly is known to getter alkali impurities. While these effects are desirable for devices fabricated using the oxidation process, these are undesirable from the standpoint of furnace monitoring because they reduce the sensitivity of the measurements.

Alkali emission from poly is also known to be longer than emission from the air/oxide interface. This contributes to an apparent reduction in alkali levels for CV compared to COS measurements that could be compensated with longer CV soak times.

Since the data was collected, a refinement to the COS measurement algorithm was generated which takes into account band bending during the mobile charge "pull" step. Without this

correction, changes in the surface voltage caused by band bending are incorrectly assumed to be due to mobile charge. A future software release will correct this issue.

Finally, the higher mobile charge observed by both CV and COS when compared to SIMS is thought to be caused by the loss of the top monolayers in the SIMS measurement due to beam stabilization issues at the beginning of the sputtering process. The future software release mentioned above will reduce the offset between COS and SIMS results.

FUTURE ENHANCEMENTS

The COS measurement technique does not require a physical contact with the wafer surface. This provides the potential for reuse of wafers, thus minimizing test wafer costs. Preliminary data shows consistency between measurement of new wafers and those reused up to five times. Additional data is necessary to determine the ultimate limit for reuse.

The addition of bulk generation and surface and bulk recombination lifetime measurements to the COS technique will provide additional tools for diagnosing diffusion furnace issues. In addition to quantifying levels of metallic impurities which can lead to bulk recombination lifetime degradation, the effects of oxidation induced stacking fault (OSF) and slip may be qualitatively and quantitatively evaluated.

SUMMARY

Large load sizes of diffusion furnaces in modern wafer fabrication facilities create the potential for significant product scrap in the event of tool contamination. The presence of contamination must be determined accurately with timeliness of the utmost importance. The substitution of high-frequency CV measurements with COS measurements has enabled the reduction in furnace contamination monitoring times from 26.5 to 2.5 hours per week with the associated increase in tool availability. The increased tool availability amounts to essentially one additional vertical furnace for every seven tool installed. In addition, the broader range of measurements available with the COS system provides additional capabilities over conventional high-frequency CV systems.

REFERENCES

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- [2] R.B. Comizzoli, J. Electrochem. Soc., Solid-State Science and Technology, 134 (2), pp. 424-429 (1987).
- [3] K. Cammull, R. Cosway, G. Horner, and B. Letherer, "Replacement of C-V Monitoring with Noncontact COS Charge Analysis", presented at the Spring 1997 MRS Conference, San Francisco, CA, April 2, 1997.

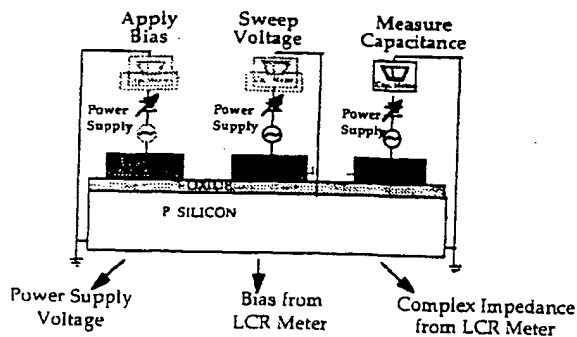


Figure 1: High-Frequency CV Measurement Technology

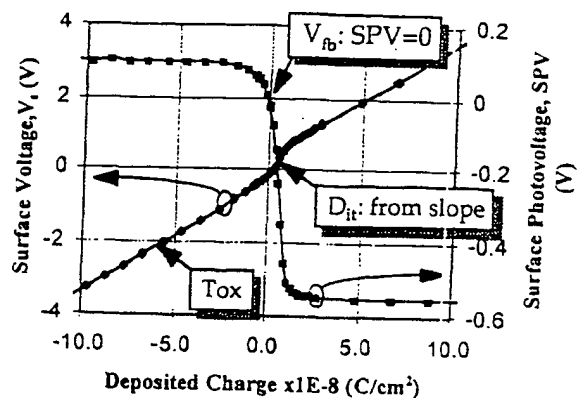


Figure 4: COS Measurement Fundamentals

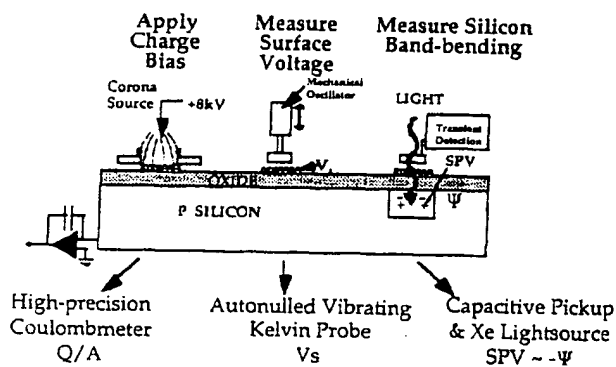


Figure 2: COS Measurement Technology

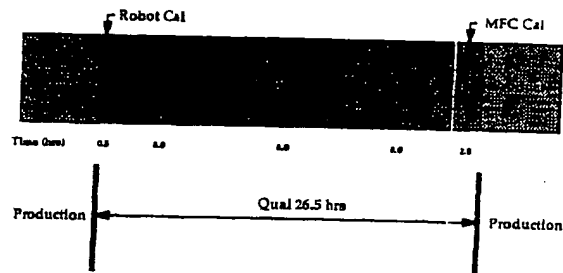


Figure 5: Original Furnace Qualification Procedure

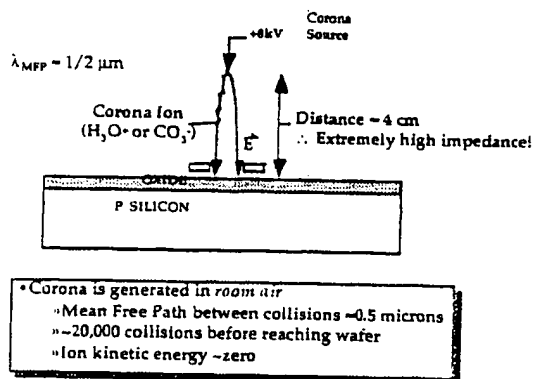


Figure 3: Application of Corona Bias

	CV	COS
System Cost (K\$)	Man.	60 -100
	Auto.	120
Throughput 3 sites/wafer (min/wafer)	90*	38
Consumables (\$/month)	3000	0

* Pairs of wafers run due to poor reliability of measurements

Figure 6: Throughput Comparison Between CV and COS Measurements

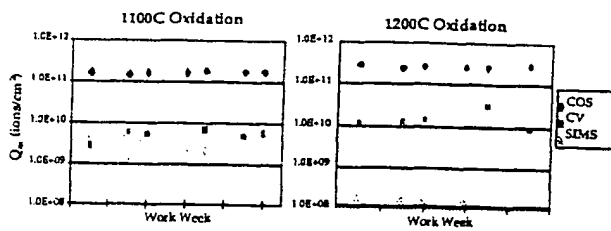


Figure 7: Mobile Charge Qualification Summary

Oxidation Temperature	1100°C		1200°C	
Measurement	CV	COS	CV	COS
Average Q _m (ions/cm²)	5.2E+09	1.6E+11	1.6E+10	2.6E+11
Stdev Q _m (ions/cm²)	7.9E+08	3.7E+10	1.9E+10	1.7E+10
Stdev (% 1-sigma)	15.3	22.8	23.7	6.5

Figure 8: Comparison of Mobile Charge (Q_m) Statistics for CV and COS Measurements

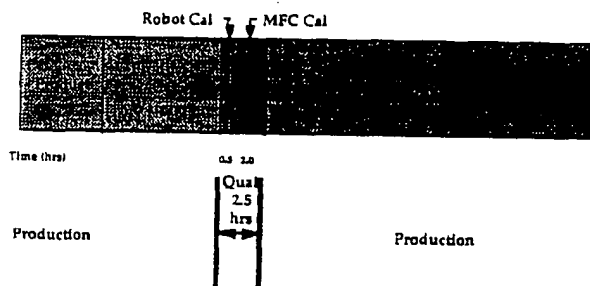


Figure 9: Revised Furnace Qualification Procedure